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VARIATIONS IN THE ABSORPTION SPECTRA  
OF ATMOSPHERIC DUST

By

G. B. Hoidale  
A. J. Blanco  
N. L. Johnson  
R. V. Doorey

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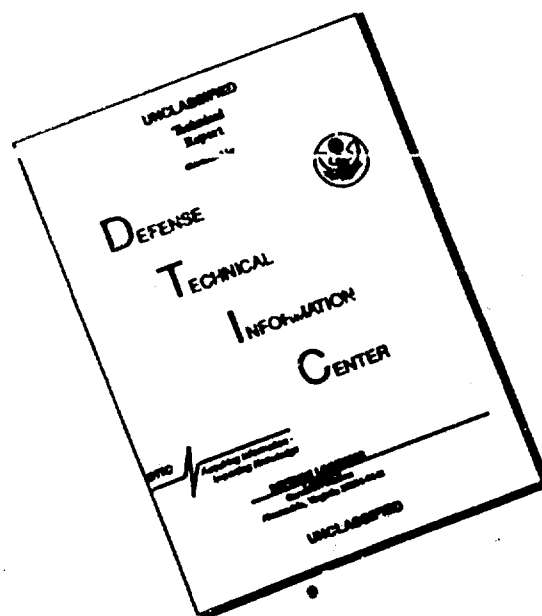
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ATMOSPHERIC SCIENCES LABORATORY  
WHITE SANDS MISSILE RANGE, NEW MEXICO

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# ABSTRACT

Six impactor and 99 membrane filter samples of atmospheric dust were collected atop a mountain in south central New Mexico during April and May 1968. Qualitative analysis of these samples by infrared absorption spectroscopy in the 4000 to  $250\text{ cm}^{-1}$  wavenumber (2.5 to  $40\text{ }\mu$  wavelength) range revealed that the positions and relative intensities of the absorption bands were dependent on the size fraction of the dust and on the time the sample was taken. Within the 1250 to  $770\text{ cm}^{-1}$  (8 to  $13\text{ }\mu$ ) atmospheric window, the micron-sized (giant) particles exhibited a peak absorption at  $1027\text{ cm}^{-1}$  ( $9.7\text{ }\mu$ ), whereas the submicron (large) particles had their peak absorption at  $1108\text{ cm}^{-1}$  ( $9.0\text{ }\mu$ ). These two absorption bands are induced, respectively, by silicate clays and by ammonium sulfate. A temporal variation was observed in the ratio of the intensities of the  $1027\text{ cm}^{-1}$  ( $9.7\text{ }\mu$ ) silicate and the  $1425\text{ cm}^{-1}$  ( $7.0\text{ }\mu$ ) carbonate absorption bands of the giant particles. This ratio was high during the early morning, at times of convective activity and precipitation, and at times of cold frontal passage from the east; it was low during the afternoon and at times of convective inactivity and no precipitation. The low ratio dust is attributed to advection of fresh soil particles from the exchange layer over the adjacent basin and mountains and the high ratio dust to advection of fresh soil particles from the Great Plains and aged soil particles from the overlying free atmosphere.

## CONTENTS

	Page
ABSTRACT - - - - -	iii
INTRODUCTION - - - - -	1
PHYSIOGRAPHIC AND METEOROLOGICAL SETTING - - - - -	2
SAMPLING PROCEDURE - - - - -	4
SPECTRAL ANALYSIS - - - - -	6
METEOROLOGICAL DATA - - - - -	10
SOURCES OF THE SAMPLED DUST - - - - -	10
TRANSLOCATING MECHANISMS - - - - -	12
METEOROLOGICAL INTERPRETATION OF A/B RATIO VARIATIONS - - - - -	13
CONCLUDING REMARKS - - - - -	17
REFERENCES - - - - -	19
APPENDIXES	
A. METEOROLOGICAL INTERPRETATION OF THE PERIOD I A/B RATIOS - - -	21
B. ATMOSPHERIC DUST CONCENTRATIONS - - - - -	29

## INTRODUCTION

Various scientific disciplines concerned with "seeing" through the earth's atmosphere in the infrared have a vested interest in those spectral intervals of relatively high transmission which have been termed atmospheric windows. Among these groups are infrared astronomers investigating "cool" celestial objects, geologists interested in thermal mapping of the earth's surface, meteorologists studying cloud systems and particulate layers, and physicists concerned with tracking and detection systems for military and civilian applications.

One of the atmospheric windows of particular interest currently is the one between  $1250$  and  $770\text{ cm}^{-1}$  ( $8$  and  $13\text{ }\mu$ ). Within this spectral interval, the absorption of energy by the dust suspended in the atmosphere is often regarded as insignificant; however, published data [1,2] show that atmospheric dust absorbs strongly in this window. Depending on the nature of the application involving this atmospheric window and depending on the associated moisture and dust conditions, the absorption of infrared radiation by the dust could be significant. Consequently, it would be advantageous to have a background knowledge of absorption spectra of atmospheric dust, of the variations in spectra as a function of particle size, time, and space, and of the role meteorological conditions play in these variations.

One geographical area over which, by virtue of generally low moisture content and occasionally high dust concentration, atmospheric dust may play an important role in the absorption of infrared energy by the various constituents of the earth's atmosphere is the southwestern United States. A spectrophotometric analysis of dust sampled near the surface of south central New Mexico [3] showed six identifiable absorption bands within the aforementioned atmospheric window, the most prominent being the silicate band at  $1027\text{ cm}^{-1}$  ( $9.7\text{ }\mu$ ). Temporal variations in the absorption spectra of the dust were reflected primarily in the ratio of the intensity of the  $1027\text{ cm}^{-1}$  ( $9.7\text{ }\mu$ ) silicate to the  $1425\text{ cm}^{-1}$  ( $7.0\text{ }\mu$ ) carbonate family absorption bands. Unresolved, however, were questions as to the size of the particles to which the dust spectra applied and as to whether the observed temporal variations in the relative intensities of the silicate and carbonate bands were meteorologically interpretable.

During April and May 1968, variations in the infrared absorption spectra of atmospheric dust were investigated through six impactor and 99 membrane filter samples of dust collected at the Mule Peak Observatory located in south central New Mexico. Using the technique of infrared absorption microspectrophotometry, the 4000 to

250  $\text{cm}^{-1}$  (2.5 to 40  $\mu$ ) absorption spectrum of each sample was obtained. The spectra revealed variations in the absorption of infrared radiation by the sampled dust, variations which were a function of particle size and meteorological conditions.

This report summarizes the results of the analysis and interpretation of the absorption spectra of those impactor and filter dust samples. After a brief description of the sampling site and sampling systems, attention is focused on the absorption spectra. The variation of spectra with particle size is presented in three absorption spectra. The temporal variation is depicted through the ratio of the intensities of the aforementioned silicate and carbonate family bands. After a discussion of dust source regions and atmospheric mechanisms responsible for the translocation of this dust, the membrane-filter sampled dust is related to source region and meteorological environment. Concomitant data on number concentrations of dust at the Observatory have been relegated to an appendix; this data was not applicable to the analysis of the dust samples and is included solely for information purposes.

To facilitate the presentation, the particle size nomenclature of Junge [4, p. 112] has been adopted, whereby the size range of atmospheric dust particles is subdivided into three groups. The particles of diameter less than or equal to 0.2  $\mu$  are AITKEN particles, those of diameter greater than 0.2  $\mu$  but less than or equal to 2  $\mu$  are LARGE particles, and those of greater than 2  $\mu$  diameter are GIANT particles.

#### PHYSIOGRAPHIC AND METEOROLOGICAL SETTING

The sampling was accomplished at the Mule Peak Observatory which is located in the Sacramento Mountains of the Guadalupe Range of south central New Mexico, almost equidistant (~1000 km) from the Pacific Ocean to the southwest and the Gulf of Mexico to the southeast (Fig. 1). The sylvan Sacramento Mountains constitute a cuesta in east-west profile with the escarpment falling abruptly in two stages from the crest near 3000 m above Mean Sea Level (m MSL) to 1200 m MSL at the floor of the Tularosa Basin to the west. The Observatory is situated atop the lower stage of the escarpment (Fig. 2) at an altitude of 2472 m MSL (32° 49' N, 105° 53' W).

By virtue of sparse vegetation and abundant, fine, and unconsolidated soil particles exposed to eolian translocation, the semidesert terrain of the Tularosa Basin affords a natural source for atmospheric particulates. Transfer of these particles into the atmosphere is effected by strong surface low pressure system winds, thunderstorm downdrafts, mountain waves, dust devils, turbulent transfer stemming from intense surface heating, etc.

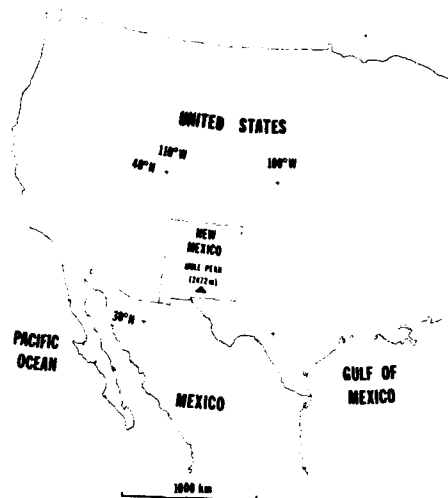


Fig. 1 Geographical setting of the Mule Peak Observatory

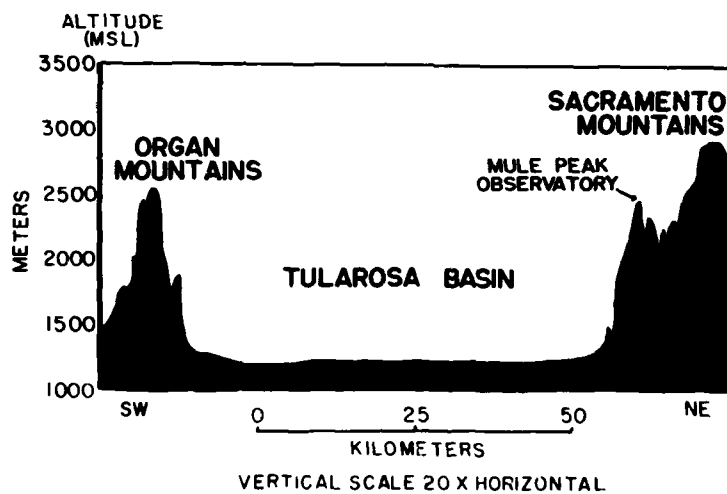


Fig. 2 NE-SW profile through the Mule Peak Observatory

During the period of sampling, the weather was, for the most part, dry, mild, and windy. Afternoon relative humidities ranged from about 5 to 50%. Temperatures generally ranged from a 10°C minimum to a 27°C maximum. Winds were predominantly from the south through the west quadrant.

#### SAMPLING PROCEDURE

The particulate sampling system consisted of three separate units: (A) an Andersen impactor sampler, (B) a sampler employing air filtration through membrane filters, and (C) a General Electric condensation nuclei counter.\* The location of each unit is indicated on the plan map of the Mule Peak Observatory shown in Fig. 3.

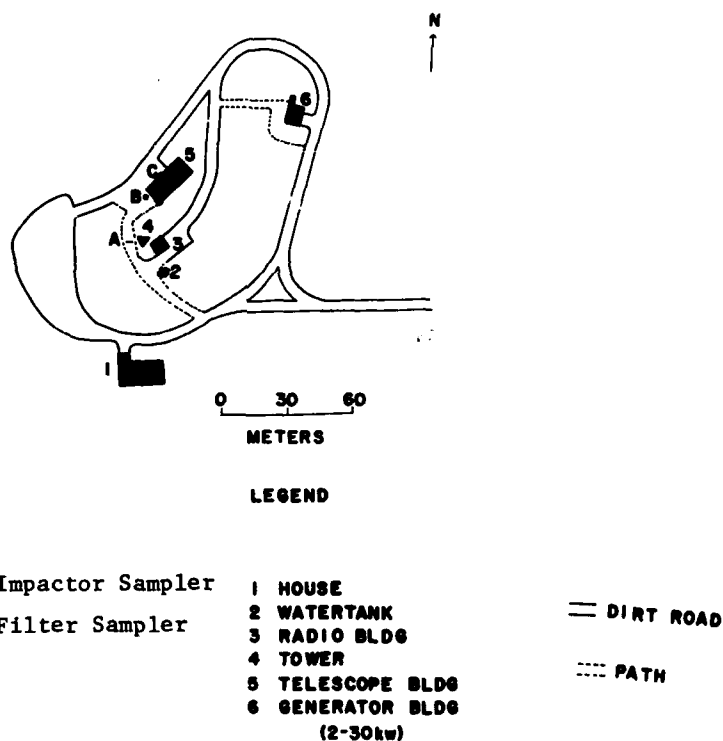


Fig. 3 Plan map of the Mule Peak Observatory

\* A description of the location of the nuclei counter at Mule Peak and the data acquired using it are provided in Appendix B.



Andersen Impactor Sampler. To obtain data on the variation of infrared absorption spectra of atmospheric dust as a function of particle size, an Andersen sampler [5] was selected as the medium of collection. This instrument is of the multistage, multijet cascade impactor type wherein particulate matter is precipitated on six 8.26 cm diameter plates. The particular model used in this study was a 110 volt, 60 cycle, nonviable particle, portable sampling unit equipped with glass plates. Table I summarizes the size sampling characteristics of this sampler for smooth, spherical particles of unit density [5, Fig. 4].

TABLE I  
Size Collection Characteristics of an Andersen Sampler  
(95% or more of particles collected on each stage)

<u>Stage</u>	<u>Diameter (<math>\mu</math>)</u>	<u>Junge Classification</u>
1	> 8.2	Giant
2	5.0 - 10.4	Giant
3	3.0 - 6.0	Giant
4	2.0 - 3.5	Giant
5	1.0 - 2.0	Large
6	0.3 - 1.0	Large

The sampler was placed at a height of 9 m above the ground, and atmospheric dust samples were taken according to the schedule listed in Table II. The duration of sampling was governed by the amount of dust required for analysis, the flow rate through the sampler, and the mass concentrations of dust encountered in the local aerosol.

TABLE II  
Andersen Impactor Sampling Schedule

<u>Sample No.</u>	<u>Dates</u>	<u>Time (LST)</u>
1	24-25 Apr	0800-0800
2	25-26 Apr	0800-0800

TABLE II CONT'D

<u>Sample No.</u>	<u>Dates</u>	<u>Time (LST)</u>
3	1- 2 May	1800-1800
4	2- 3 May	1800-1730
5	16-17 May	0600-0600
6	17-18 May	0600-1200

Membrane Filter Sampler. To investigate temporal variations in the infrared absorption spectra of atmospheric dust, the dust was sampled by air filtration through membrane filters. The filters were of 0.8  $\mu$  maximum diameter pore size and had an effective filtering area of 278 mm<sup>2</sup>. The filters were enclosed in a vaned mount and were placed 3.5 m above the ground.

With this sampling system and for the mass concentrations of dust to be expected at the Observatory, the requisite amount of sample for analysis could be obtained in six hours. The six-hour periods, designated by Roman numerals, were as follows: Period I, 0000-0600 Local Standard Time (LST); II, 0600-1200 LST; III, 1200-1800 LST; and IV, 1800-2400 LST. From 23 April to 19 May 1968, 99 six-hour samples were taken.

#### SPECTRAL ANALYSIS

The 4000 to 250 cm<sup>-1</sup> (2.5 to 40  $\mu$ ) infrared absorption spectrum of each dust sample was obtained by following a microspectrophotometric technique which required 50 to 100  $\mu$ g of sample [3]. No attempt was made to isolate any water soluble or organic fractions. All spectra were run on a Perkin-Elmer Model 521 double beam infrared grating spectrophotometer equipped with a 6X beam condenser.

The absorption spectra contain the combined effects of the dust and the potassium bromide (KBr) matrix in which the dust is suspended. The KBr has a uniform, high transmission throughout most of the spectral region investigated and is evident in the spectra only as a decrease in transmission between 300 and 250 cm<sup>-1</sup> (33 and 40  $\mu$ ), i.e., the absorption bands presented are believed to be due solely to the dust.

Andersen Impactor Samples. Examination of the absorption spectra of the Andersen dust samples revealed a transition in the absorption

band positions of the dust from the first four through the last two stages. The results are summarized in Fig. 4. The curves therein are of the sample of 16-17 May which has been selected as representative of the transition observed in all six samples. Curve A is an absorption spectrum representing the nearly identical spectra of dust from the first four stages (giant particles). Curves B and C are the spectra, respectively, of the stage 5 and stage 6 large particles. To portray the transition which occurs, emphasis is placed on the absorption bands designated as a, b, c, and d and which are centered, respectively, at 1425, 1399, 1108, and 1027  $\text{cm}^{-1}$  (7.0, 7.1, 9.0, and 9.7  $\mu$ ).

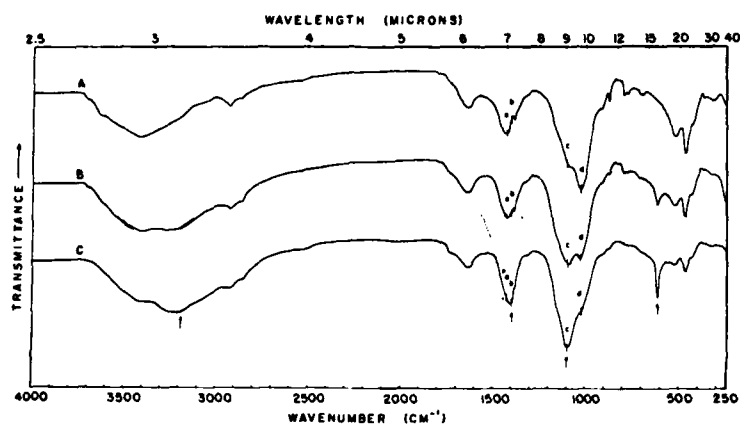


Fig. 4 Spectrogram tracings of atmospheric dust collected with an Andersen sampler, 16-17 May 1968; Curve A: stages 1-4; Curve B: stage 5; Curve C: stage 6.

The change in the pattern of absorption is particularly evident in the 1250 to 770  $\text{cm}^{-1}$  (8 to 13  $\mu$ ) atmospheric window where the strongest absorption band shifts from band d for the giant particles (curve A) to band c for the large particles (curves B and C).

Curves A, B, and C may be used to ascertain the composition of the dust. First of all, curve A is nearly identical to the representative dust spectrum of Blanco and Hoidale [3], both in the positions and relative intensities of the absorption bands. Therefore, their representative dust spectrum appears to apply to giant particles. These particles are spectrally dominated by the silicate clays illite, kaolinite and montmorillonite, the carbonate calcite and the silicate quartz [3]. Secondly, curve B, although similar to curve A, shows ammonium sulfate  $[(\text{NH}_4)_2\text{SO}_4]$  absorption bands at 3125, 1399 (band b), 1108 (band c), and

618  $\text{cm}^{-1}$  (3.2, 7.1, 9.0 and 16.2  $\mu$ ). By curve C,  $(\text{NH}_4)_2\text{SO}_4$  has become the dominant selectively absorbing constituent as indicated by the arrows. This result tends to confirm the finding by Junge [4, p. 170] that the soluble portion of the large particle fraction of atmospheric dust is dominated by  $(\text{NH}_4)_2\text{SO}_4$ .

Band c merits further comment because it appears to be present in curve A. In curve A the shoulder at 1087  $\text{cm}^{-1}$  (9.2  $\mu$ ), which might be construed as  $(\text{NH}_4)_2\text{SO}_4$  induced, is, in reality, a silicate band. Also, band c, although one of the fingerprint absorption bands of  $(\text{NH}_4)_2\text{SO}_4$ , is a sulfate family band common to calcium sulfate (gypsum) and sodium sulfate (mirabilite-thenardite) which are occasionally observed in spectra of airborne dust from south central New Mexico [3].

The sharp absorption band at 1383  $\text{cm}^{-1}$  (7.2  $\mu$ ) in curves A and B is nitrate in origin. The almost complete disappearance of this band by the final stage dovetails Junge's data [4, p. 171] on the small nitrate content of the large particle fraction.

Membrane Filter Samples. Examination of the absorption spectra of the 99 six-hour membrane filter dust samples revealed that: (1) the spectra conformed to the representative dust spectrum [3] in the occurrence and position of the absorption bands and (2) the primary interspectral variations once again involved the relative intensities of the silicate clay and carbonate family bands.

The interspectral variations were quantified by means of an arbitrarily designated A/B ratio [3], a number which, as measured on a given spectrum, represents the relative intensity of the silicate clay and carbonate family absorption bands centered at 1027 and 1425  $\text{cm}^{-1}$  (9.7 and 7.0  $\mu$ ), respectively. A value of two for the A/B ratio would signify that the absorption band of the silicate clays is twice as strong as the carbonate band.

The A/B ratios for the 99 dust samples are chronologically displayed in Fig. 5. In general, the ratios are highest in the early morning hours and lowest during the afternoon. A more elusive feature, perhaps, is the longer aperiodic variation on which the diurnal variation appears to be superposed. The aperiodic variation is indicated on Fig. 5 by the dashed-line channel. The width of the channel, 1.0, is the mean daily range for the 21 calendar days having the full complement of four 6-hour samples; the position of the channel was governed by the Period II, III, and IV A/B ratios and not the rather more excursive Period I ratios.

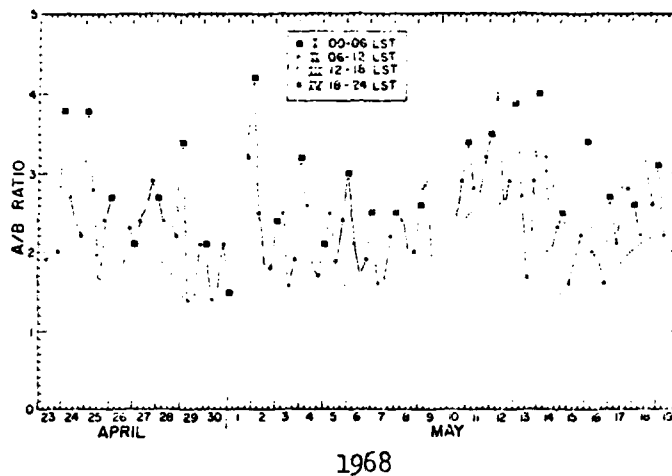


Fig. 5 Temporal variation of the A/B ratio, Mule Peak Observatory,  
April and May 1968

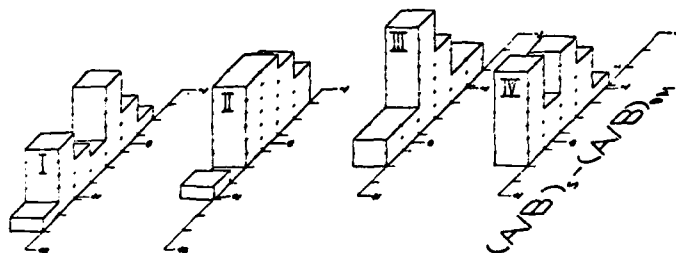


Fig. 6 Frequency distribution of the differences in A/B ratio between the  
daily mean and the sample for the Period I, II, III, and IV samples taken  
during the 21 full-complement (four sample) days (each block represents  
one sample)

## METEOROLOGICAL DATA

In reconstructing the meteorological pattern associated with Fig. 5, both surface and upper air observations were utilized. At the Observatory, weather data were limited to wind direction and visual observations of sky condition and visibility, but from one site on each side of the floor of the basin there were standard hourly observations of sky condition, visibility, weather, temperature, moisture and wind. Surface weather charts were used to trace air mass and frontal movements.

The circulation aloft was determined from military rawinsonde observations and 700 mb pressure surface charts. The rawinsonde observations were irregularly scheduled but did average four soundings per day. These soundings were scattered among five different release points located on the floor of the basin within 70 km of Mule Peak. The 700 mb charts gave the general circulation at about the height of the surrounding ridges.

## SOURCES OF THE SAMPLED DUST

Analysis of the meteorological conditions associated with the temporal variations in the A/B ratio led to the conclusion that these variations could be interpreted in terms of source regions and atmospheric transfer mechanisms. The source regions fell into four categories: (1) exchange layer of relatively low A/B ratio dust above the Tularosa Basin, (2) exchange layer of low ratio dust over the Sacramento Mountains, (3) exchange layer of high ratio dust over the exposed soils of the western Great Plains, and (4) overlying free atmosphere with its high ratio dust.

For several reasons it seemed reasonable to attribute much of the dust collected at Mule Peak to the soils of the 60-km wide Tularosa Basin. First of all, that the basin soils act as a source for airborne dust over the local area had been visually confirmed on numerous occasions in the past, especially during the dry and windy spring months. Secondly, the predominant southwesterly to northwesterly winds aloft over the basin during April and May could, in turn, transport these particles to the altitude of the sampler. Furthermore, Blanco and Hoidale [3] had shown a close similarity between the infrared absorption spectra of dust samples simultaneously collected at Mule Peak and at a site situated on the western edge of the floor of the Tularosa Basin.

Judging from the wide range of the A/B ratios (1.0 to 23.7) for the small particle fraction of 25 soil samples taken from the basin floor

area [3] within a southwest through northwest sector extending 120 km radially from the Observatory, the likelihood of one A/B ratio sufficing to characterize the dust of the exchange layer over the Tularosa Basin seemed remote. However, because of natural intermixing in translocation of particles from the myriad (with respect to A/B ratio) of soils which contribute dust to the local atmospheric aerosol, it is reasonable to expect that with respect to an atmospheric dust sampling site well removed from the floor of the basin, such as the Mule Peak Observatory, the basin floor dust could be characterized by one A/B ratio. For 265 atmospheric dust samples collected 3.5 m above the ground at a site on the western edge of the floor of the Tularosa Basin, Blanco and Hoidale [3] had shown a range from about 1 to 10 and a mean of about 2 in A/B ratio. If it is assumed that this 18-month mean reflects a composite contribution from the basin soil sources, than a value of 2 might be assigned to the A/B ratio of atmospheric dust in the exchange layer over the basin.

Another source of the Mule Peak dust is the comparatively weak (with regard to spatial extent) exchange layer over the adjacent mountains. This layer receives some particles from the vegetally dominated underlying surface, but apparently the greatest contribution is from the particle-rich aerosol over the adjacent basin. The A/B ratios of soil samples taken near the base of the dust sampler at Mule Peak and from atop a mountain 90 km northeast of Mule Peak were, respectively, 2.0 and 2.1. It appears that the A/B ratio of the mountain boundary layer is basically low, but that it fluctuates in response to changes in the ratio at equivalent altitudes over the basin proper.

A third source region is the exchange layer over the western Great Plains. Limited data obtained by Hoidale et al. [6] suggest that these plains are sources of dust rich in silicate clays which would thereby imply a high A/B ratio.

The remaining source region, if indeed it may be treated as separate and distinct, seems to be the free atmosphere which overlies the exchange layer. The particles suspended therein may represent an intermixed contribution of soil particles from a number of world-wide sources. Thus, the dust of this extensive layer could realistically be expected to have an A/B ratio which differed from the A/B ratio of dust from any given local soil source, such as that covered in this study. The particles of the free atmosphere may be considered as aged continental particles and appear to be characterized by an A/B ratio which is high relative to that of the composite Tularosa Basin surface dust, i.e., it is relatively deficient in carbonates.

In summary, the soils of the basins and mountains in the immediate vicinity of the sampler will be regarded, in toto, as sources of low A/B ratio dust. The soils of the western Great Plains and the free atmosphere itself are treated as high A/B ratio sources.

## TRANSLOCATING MECHANISMS

Four atmospheric mechanisms were considered to be primarily responsible for the vertical variation in the silicate clay-carbonate composition of the dust over south central New Mexico, variations which were reflected in the A/B ratios of the Mule Peak dust samples. The four mechanisms are: (1) daily cycle of turbulent exchange, (2) precipitation, (3) convective activity, and (4) frontal activity.

Foremost of the atmospheric processes responsible for establishing the variation of A/B ratio with height above the bolson floor, i.e., the extent of coupling between the low ratio dust of the exchange layer and the high ratio dust of the overlying free atmosphere, is the daily cycle of turbulent exchange, whereby surface dust is lifted during the day and settles toward the surface at night. The vertical extent of this "turbulent transfer layer," often referred to as mixing depth, is dependent on surface heating and lapse rate. As a consequence, the mixing depth undergoes diurnal and seasonal pulsations, the greatest upwelling occurring during the afternoon and during summer. The estimates of mixing depth by Holzworth [7] indicate that on the average over this area during the period from mid-April to mid-May the mixing depth ranges from 300 m above the surface in the early morning to 2900 m during the afternoon.

With respect to the A/B ratio, an effect of this transfer would be to lift the low ratio surface dust to progressively higher altitudes over the basin during the daylight hours. Thus, the Mule Peak Observatory, at 1250 m above the basin floor, would, on the average for the mid-April to mid-May period, be engulfed by this layer from about midmorning until early evening. This was reflected in the mean A/B ratio of 2.0 for the Period III dust samples. During the course of the day, the sampler could also be within the much less vertically developed mixing layer over the mountains themselves or even within the free atmosphere. With respect to the 6-hour dust samples, the latter condition would be more likely to occur during Period I and would be seen as a high A/B ratio.

Another factor involved in the vertical variation of the A/B ratio is precipitation, which acts as a giant particle scavenger. Moreover, although the precipitation impinging on the basin floor may initially release particles into the atmosphere, it generally serves to wet the surface, thereby agglomerating particles and preventing their release. However, because of the porous condition of the local soils and the often dry, sometimes windy nature of the local atmosphere, the suppressant effect may be short lived. An effect of the scavenging and agglomeration would be to increase the A/B ratio of the dust sampled at Mule Peak by virtue of the resultant decrease in the number concentration of exchange layer dust relative to the concentration of free atmospheric dust.



The third factor is convective activity. Generally a temperature inversion, such as that which occurs at the upper boundary of the mixing layer, acts as a barrier to the flux of particles across this thermal discontinuity. However, convective clouds may penetrate these "barriers" and by virtue of their attendant vertical motions mix the precipitation-depleted low ratio dust from below with the higher ratio dust from above. The effect of this factor would be to increase the ratio of silicate clays to carbonates in the mixing layer and to decrease the ratio in the free atmosphere. The magnitude of the interchange of particles would be a function of the extent and intensity of the convective activity.

In contrast to the "regularity" in temporal variation of the A/B ratio imposed by the daily turbulent cycle, the effect of convective activity and precipitation would tend to be aperiodic because of temporal and spatial irregularities in their occurrence over this area. An estimate of the combined effect of convective activity and precipitation on the A/B ratio of the Mule Peak dust may be obtained from visual observations of the areal and vertical extent of cumuliiform cloudiness and precipitation.

The fourth factor is frontal activity. Although fronts pass across south central New Mexico from all directions, it is the cold fronts moving across from the east which cause the most significant changes in the A/B ratio. These incursions may have tapped the western Great Plains of its assumed high A/B ratio dust, the magnitude depending on the condition of the soil surfaces and on the concomitant meteorological conditions. Because of the irregular topography of this area, it is sometimes difficult to trace the westward progression of these cold fronts and, as a result, they may or may not be carried on surface weather maps. However, by detailed analysis of the local meteorological data, it was possible to pinpoint the passage of these fronts over this area.

#### METEOROLOGICAL INTERPRETATION OF A/B RATIO VARIATIONS

With the foregoing two sections as background, it is now possible to offer a rationale for many of the features illustrated in Fig. 5. Three features to be considered are: (1) the diurnal variation in the A/B ratio, (2) the wide fluctuations of the Period I ratios from the dashed-line channel, and (3) the meanderings of the channel itself. These features are particularly illustrative of the atmospheric factors and the interplay of these factors which appear to govern the ratio of silicate clays to carbonates in the dust sampled at Mule Peak.

The apparent diurnal variation may be brought into closer perspective by calculating the mean A/B ratio for each of the four sampling periods

for the 21 calendar days when a full complement of four 6-hour samples was taken. As seen in Table III, the ratio reaches its highest value during the six hours prior to sunrise and its lowest during the six hours preceding sunset.

The latter period is generally the time of maximum vertical extent of the exchange layer. On the average for this time of year this envelope of low A/B ratio dust over both the basin and the mountains would extend much higher than the Mule Peak Observatory during the entire afternoon. Thus, almost irrespective of wind direction, the dust sampled at Mule Peak during these hours would exhibit a low A/B ratio. At night, however, this envelope contracts and surface winds generally subside. As the mixing layer effectively dips below the altitude of the Observatory, the free atmosphere, with its attendant high A/B ratio dust, draws closer to the ground. Therefore, winds at the sampler having a component from the basin (the prevalent condition) could advect in dust of progressively higher A/B ratio as the night progressed. Flow off the adjacent mountains, however, would continue to tap the low ratio dust of the mountain boundary layer. This simplistic explanation is, obviously, conditioned in reality by other interrelationships, but it does offer a reason for the diurnal component.

TABLE III

Arithmetic Mean A/B Ratio for the Four  
Dust Sampling Periods for 21 Days

<u>Period (LST)</u>	<u>A/B (n=21)</u>
I (00-06)	3.0
II (06-12)	2.4
III (12-18)	2.0
IV (18-24)	2.3

To show the diurnal variation of the A/B ratios in another perspective, the effect of the aperiodic variation was eliminated by a normalization process whereby, for each of the 21 full-complement days, the four-sample mean A/B ratio for a given day,  $(A/B)_{DM}$ , was subtracted from the ratio for each of the four sampling periods therein,  $(A/B)_S$ . The frequency distribution of these differences is shown in Fig. 6. A striking feature of this figure is the bimodal distribution, statistically indicating samples from two populations, of the differences during the nighttime hours (Periods I and IV). To account for the bimodal distribution and because they exhibited the greater fluctuations,

the A/B ratios of the Period I samples were selected for meteorological interpretation.

Examination of the meteorological conditions existing during the 24-30 hours preceding each of the 25 Period I samples led to the conclusion that the two populations involved were low ratio dust from the basin or mountain exchange layer and high ratio dust from the free atmosphere or from the western Great Plains. By terming an A/B ratio "high" or "low" depending on whether it was above or within the dash-line channel of Fig. 5, and not on absolute value, it was found that the sampled dust could be typed by A/B ratio, source region, and meteorological conditions. This led to a categorization of the dust sampled at Mule Peak into four types ( $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\Delta$ ) corresponding to the four source regions (Table IV). The meteorological conditions attending the presence of each of the four types of source region dust at the sampler are summarized below.

TABLE IV  
Type Classification of Mule Peak Dust

<u>Type</u>	<u>Source Region</u>	<u>A/B Ratio</u>
$\alpha$	Free atmosphere	high
$\beta$	Basin exchange layer	low
$\gamma$	Western Great Plains	high
$\Delta$	Mountain exchange layer	low

Type  $\alpha$ . Type  $\alpha$  is characterized by limited (with respect to the height of Mule Peak above the floor of the basin) vertical transport of the low ratio surface particles during the preceding afternoon. This limitation may be imposed by precipitation, thermal discontinuities, light surface winds or a combination of these factors. In addition, the wind flow at the sampler must exhibit a component from the west to transport the relatively low lying free atmospheric dust from over the Tularosa Basin to the filter.

Type  $\beta$ . Type  $\beta$  is characterized by pronounced vertical transport of the low ratio surface particles during the preceding afternoon. This transport is often associated with near dry adiabatic lapse rates from the surface of the basin to at least the altitude of Mule Peak and moderate to strong winds which may persist until long after sunset, the time when the surface winds normally diminish rapidly in speed over this area. Furthermore, the wind at the sampler must exhibit a westerly component so as to tap dust from this billowing envelope of low ratio dust.

Type  $\gamma$ . Type  $\gamma$  is characterized by northeasterly to easterly winds at the sampler during Period I. Such winds often denote the passage of a cold air mass which, as it traversed the western Great Plains, picked up high ratio dust from the exposed soils unless the soils were snow-covered or water-soaked.

Type  $\Delta$ . Type  $\Delta$  is characterized by southeasterly to easterly winds at the sampler during Period I. The overall level of the A/B ratio within the mountain boundary layer is influenced by the basin dust.

Each of the 25 Period I A/B ratios fell under one of these types (Table V). Appendix A contains meteorological synopses for the individual samples.

As previously noted, the diurnal component of the temporal variation of the A/B ratio seems to be superposed on longer aperiodic variations. Although the exact position of the dashed-line channel of Fig. 5 is open to question, certain features of the aperiodic component appear to be unequivocal. Foremost of these is the gradual increase in the A/B ratio from 6-7 May to 12 May and the subsequent, but more rapid, decline to 15-16 May.

Examination of the attendant meteorological data revealed a gradual increase in convective activity from the cumuliiformless 6-8 May period to widespread activity on 11-12 May. By the 13th only a few early morning fair weather cumulus clouds topped the mountains. Skies remained free of cumulus-type clouds until the 16th when fair weather cumulus clouds reappeared over the flanking mountains.

TABLE V  
Distribution by Meteorological Type of  
the Period I A/B Ratios

<u>Type</u>	<u>Dates</u>
$\alpha$	April 24, 25; May 2, 6, 13, 14, 16
$\beta$	April 26, 27, 28; May 3, 7, 15, 17
$\gamma$	April 29; May 4, 11
$\Delta$	April 30; May 1, 5, 8, 9, 12, 18 19

Another period of convective activity, albeit much weaker, extended in a similar gradually increasing fashion from 30 April to 4 May and may account for the slight channel maximum of 3-4 May.

The evidence for the convective inducement of the aperiodic variations in the A/B ratio is not strong, but it does appear to be reasonable: the resultant precipitation agglomerates the soil particles; the associated vertical motions mix the lowered concentration, low ratio surface dust with the low concentration, high ratio dust of the free atmosphere.

#### CONCLUDING REMARKS

In evaluating the results of this qualitative infrared spectroscopic study of airborne dust, several comments in regard to the dust spectra are in order. Perhaps the most important is that the infrared spectral determination of the particulate composition of the local atmospheric aerosol includes only those minerals or compounds which possess a number of significant (fingerprint) absorption bands within the 4000 to 250  $\text{cm}^{-1}$  (2.5 to 40  $\mu$ ) spectral interval and which occur in concentrations high enough for detection. Thus, for example, no mention could be made of sodium chloride because of its lack of absorption bands within the region of interest. Secondly, some minerals, such as opal, have absorption bands overlapping those of the identified components and, as a consequence, are difficult to identify.

The actual assessment of the absorptive effect of airborne dust on the transmission of infrared energy through the earth's atmosphere is beyond the scope of this report. However, a few qualitative inferences are possible.

Over south central New Mexico the strongest absorption band of the giant particle aggregate in the 4000 to 250  $\text{cm}^{-1}$  (2.5 to 40  $\mu$ ) range is in the 1250 to 770  $\text{cm}^{-1}$  (8 to 13  $\mu$ ) atmospheric window at 1027  $\text{cm}^{-1}$  (9.7  $\mu$ ). This observation is in agreement with the absorption spectra of atmospheric dust sampled in Germany and Japan [1,2]. An implication of this observation is that the absorption spectra of dust from south central New Mexico may be more representative of global conditions in the lower troposphere than might be expected.

Since giant particles settle out of the atmosphere relatively rapidly and are greatly subject to precipitation scavenging whereas the large particles represent a more permanent component of the atmosphere, it might be concluded that certain atmospheric conditions, such as light wind and a low level of turbulence (nighttime), might foster a shift in peak absorption within the "window" from the giant particle peak at 1027  $\text{cm}^{-1}$  (9.7  $\mu$ ) to the 1108  $\text{cm}^{-1}$  (9.0  $\mu$ ) peak characteristic of large particles.

The relative intensities of the 1027  $\text{cm}^{-1}$  (9.7  $\mu$ ) and the 1425  $\text{cm}^{-1}$  (7.0  $\mu$ ) giant particle absorption bands vary with height in response

to time of day and soil and meteorological conditions, at least over south central New Mexico. A similar pattern could occur over other geographical areas depending on the relative intensities of the silicate clay and carbonate fractions of the dust near the surface and aloft.

Further generalizations as to the applicability of the data inherent within or implied by this study must await not only other studies of the infrared absorption spectra of airborne dust and the small particle fraction of source region soils, but also concomitant data on the size distribution and number concentration of the individual constituents of atmospheric dust. With respect to the propagation of monochromatic radiation, the existence of fine structure in the absorption spectra of the dust should be investigated.

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## APPENDIX A

### METEOROLOGICAL INTERPRETATION OF THE PERIOD I A/B RATIOS

This appendix presents a meteorological interpretation of the A/B ratios of the Period I dust samples which were listed in Table V of the text. Following the date of the sample is the corresponding A/B ratio, the word "high" or "low" to indicate whether the ratio was above or within the dashed-line channel of Fig. 5, and the type classification. The meteorological conditions refer to the 12-24 hours preceding the sampling.

24 April 1968	3.8	HIGH	$\alpha$
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Shortly before sunrise on 23 April, stratiform clouds began to develop. By sunrise skies became broken, by 0900 LST light rain was general over the area and by sunset skies were cloud free. Surface winds were light to moderate, shifting from southerly to northerly as the day progressed. It appears that the vertical transfer of giant particles from the basin soil into the atmosphere was inhibited by the agglomeration and scavenging effects of the precipitation and by a stable thermal regime over the basin. Therefore, under clear skies and light northwesterly winds at the sampler and aloft over the basin the next morning, the high A/B ratio could represent predominantly aged free tropospheric continental particles.

25 April 1968	3.8	HIGH	$\alpha$
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As on the 24th, meteorological conditions did not appear to be conducive to vertical translocation of the giant soil particles. Skies were clear and there was a pronounced drying in the lower levels, but surface winds were light (southerly) and the thermal regime remained stable. With little vertical transport of low A/B ratio dust from the exposed soils, the southerly flow at the sampler and the southwesterly flow over the basin proper could once again prove favorable for the presence of aged high A/B ratio dust during Period I on the 25th.

26 April 1968	2.7	LOW	$\beta$
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With respect to the dashed-line channel, the A/B ratios of the Period I samples of 26, 27 and 28 April differed markedly from the first two samples, thus suggesting a change in the attendant meteorological conditions. On the 25th skies were clear, the lower atmosphere continued to dry and, for the first time since the sampling began, dry adiabatic lapse rates were reached during the afternoon. After a morning of light and variable winds, the pattern became one of moderate to



strong westerly winds until nearly midnight. Thus, the northwesterly winds at the sampler could be tapping low A/B ratio surface dust which had "boiled" off the basin floor the previous afternoon.

27 April 1968                      2.1                      LOW                      β

Strong westerly to southwesterly winds across the floor of the basin during the afternoon of 26 April gave rise to blowing dust from noon until shortly after sunset. Moreover, the strong surface winds persisted until nearly midnight. Therefore, sedimentation would have had little chance to take effect so that the northwesterly winds at the sampler the next morning were carrying primarily basin floor dust.

28 April 1968                      2.7                      LOW                      β

The meteorological pattern of clear, dry, unstable air continued through the 27th. Westerly surface winds were stronger and persisted longer than on the 25th and gave rise to blowing dust across the basin floor during the afternoon. Once again northwesterly winds at the sampler could be carrying primarily basin floor dust which would result in a continued low A/B ratio during Period I on the 28th.

29 April 1968                      3.4                      HIGH                      γ

The 28th of April was characterized by a marked change from the meteorological pattern of clear skies, moderate to strong southwesterly to westerly winds, and blowing dust which had persisted for the previous three days. Over the floor of the basin there was an influx of cooler, more moist and more stable air from the north early in the day. This change bore the earmarks of a cold frontal passage although it was not so designated on surface weather charts. With the exception of scattered afternoon cumulus clouds, skies were clear. The northerly winds persisted over the floor of the basin throughout the day and resulted in isolated patches of blowing dust during the afternoon. At Mule Peak, however, wind directions remained southwesterly to northwesterly until just after sunset when the cooler air cascaded in from the northeast implying that the initial surge of cooler air over the basin was quite shallow. This shallow layer of cool, stable air displaced the lower portion of the deep layer of surface dust which had blanketed the basin for the three previous days and inhibited extensive vertical transfer of dust from the surface even though wind speeds were initially high enough to dislodge the giant soil particles. At Mule Peak the influx of air from the northeast brought in high ratio dust from the western Great Plains thereby accounting for the departure from the channel.

30 April 1968	2.1	LOW	Δ
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On the 29th of April, skies were virtually cloudless and basin surface winds were light and variable, the result of the movement of a surface high pressure system over the area. As a consequence, extensive vertical transfer of the giant basin soil particles was not favored. That the free atmosphere did not engulf the sampler the following morning is attributed to the southeasterly to southerly winds at Mule Peak maintaining the low A/B ratio mountain boundary layer over the sampler during Period I.

1 May 1968	1.5	LOW	Δ
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The same comments apply as to the 30th of April.

2 May 1968	4.2	HIGH	α
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On the morning of 2 May the ratio rose to 4.2, the highest of the 25 Period I A/B ratios. Convective activity in the form of scattered precipitating cumuliiform clouds was observed from sunrise until noon, became moderate southwesterly for a few hours prior to sunset, but no blowing dust was reported. The vertical transport of basin floor dust was inhibited and thus the westerly flow at Mule Peak could now tap the free atmosphere over the basin.

3 May 1968	2.4	LOW	β
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With one notable exception conditions were once again not favorable for extensive vertical transfer of basin dust. Surface winds were stronger and persisted longer (0200 to 2400 LST) than on the previous day, but there were no reports of blowing dust during the daylight hours. However, convective activity appeared to be more extensive than on the 2nd and lasted until nearly midnight along the eastern flank of the basin where post sunset surface visibilities were restricted by blowing dust. Light northwesterly winds aloft could then have transported this low A/B ratio, thunderstorm engendered, basin dust to the sampler.

4 May 1968	3.2	HIGH	γ
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The basic pattern of cloudiness and late evening thunderstorm activity continued. Blowing dust was associated with late afternoon and early evening thundershowers. Around sunset a cold front passed over the floor of the basin; several hours later this polar air reached the sampler from the northeast. That the ratio was not higher might be attributed to the weakness of the cold front and/or mixture of the high ratio dust from the east with the lower ratio basin dust which was being transported to the sampler by light westerly winds prior to the frontal passage.

5 May 1968                      2.1                      LOW                      Δ

The polar air continued to penetrate the basin until mid-afternoon when the light southeasterly flow veered to moderate southwesterly. Convective activity, although diminished in intensity and areal extent, was once again in evidence and did result in localized blowing dust for several hours around sunset. At Mule Peak the winds were southeasterly, thereby indicating a tapping of the Sacramento Mountain boundary layer dust and a consequent low A/B ratio during Period I on the 5th.

6 May 1968                      3.0                      HIGH                      α

By the 5th, convective activity had been reduced to scattered fair weather cumulus clouds over the surrounding mountains and drying had begun in the low levels. Under a canopy of broken cirrostratus clouds, surface winds were moderate southwesterly from 1000 to 2000 LST. Some blowing dust was reported along the western edge of the basin. Considering the basin source region as a whole, this might indicate weak vertical penetration of the basin dust so that the southwesterly winds at the sampler the following morning could be bringing in a mixture of boundary layer and free atmospheric dust to Mule Peak.

7 May 1968                      2.5                      LOW                      β

The drying continued. After mid-morning skies were clear. Strong southwesterly winds throughout the day and early evening raised clouds of dust from the basin floor. Visibilities were restricted to less than 15 km from 1600 to 2200 LST. Coupled with a favorable thermal structure this would indicate the most extensive vertical transport of basin dust since 26-27 April. Thus, the northwesterly winds at the sampler the following morning would be expected to bear predominantly low A/B ratio basin surface dust.

8 May 1968                      2.5                      LOW                      Δ

Around sunrise on the 7th modified polar maritime air crossed the basin from the northwest. This resulted in a few hours of blowing dust near noon. Thereafter, however, the northwesterly winds diminished rapidly in speed. Skies were clear until noon, but by mid-afternoon the sky was thin overcast in cirriform clouds. The Period I sampler winds were southerly to southeasterly indicating an apparent tapping of the dust envelope over the Sacramento Mountains although the low ratio may also reflect residual basin dust from the extensive transfer of the 6th.

9 May 1968

2.6

LOW

Δ

Vertical transfer of basin dust was not favored on the 8th. Skies were broken to overcast in cirriform clouds and winds near the floor of the basin were light and variable except for moderate southerly flow from 1200 to 1800 LST. The southerly flow at the sampler may once again have tapped the Sacramento Mountain boundary layer.

11 May 1968

3.4

HIGH

γ

No dust sample was collected on the morning of the 10th. However, the daily weather summary is continued for the sake of continuity and for understanding the rapid increase in A/B ratio which culminated on the 12th. On the 9th skies were scattered to broken in altocumulus and overcast in cirriform clouds. The reemergence of convectivity was signaled by the appearance of isolated cumulus clouds in various stages of development over the surrounding mountains. Surface winds were moderate southwesterly prior to noon, then shifted to northwesterly with the overpassage of a weak trough.

The 10th was marked by the passage of a weak cold front from the northeast and a continued increase in convective activity. Early in the day a northwest-southwest oriented cold front moved slowly across the basin. However, the penetration of colder air was brief as attested to by southwesterly winds from the surface to ridge height by noon. Convectively, early morning cumulus clouds rapidly developed into cumulonimbus clouds. The ensuing rain showers began before noon and localized blowing dust was reported near sunset; the convective activity ended by 2100 LST. Shortly before midnight the cooler air, which had been displaced earlier in the day, reappeared at Mule Peak and over the surface of the basin. This would account for the numerically high A/B ratio. The fact that this ratio is a borderline case with respect to the dashed-line channel of Fig. 5 suggests that there has been a mixing with the already high ratio dust over the basin proper.

12 May 1968

3.5

LOW

Δ

By mid-morning on the 11th the cooler air had been reinforced by a fresh surge of polar air from the southeast. This resulted in moderate south southeasterly flow from the surface to ridge height until shortly after sunset. Convective activity, although beginning later in the day than on the 10th, appeared to be more intensive and extensive with thunderstorms continuing well past midnight. The thunderstorms caused some blowing dust during the middle of the afternoon. At the sampler the southeasterly winds indicated tapping of the boundary layer over the mountains. However, this layer contained relatively high ratio dust, probably representing the combination of the high ratio dust from the east and the settled dust of convective mixing.

13 May 1968

3.9

HIGH

$\alpha$

On the 12th there was a marked decrease in convective activity. The cumulonimbus stage was reached by mid-afternoon, but was confined to the eastern edge of the basin where isolated patches of blowing dust were spawned. Across the basin there was a nearly stationary north-south oriented front. To the east of the front winds were moderate south southeasterly and dewpoints were at the highest levels of the entire sampling period; to the west winds were southwesterly and dewpoints some 14°C lower. The southwesterly winds at the sampler the next morning apparently brought in free atmospheric dust.

14 May 1968

4.0

HIGH

$\alpha$

The localized nature of the blowing dust and the good visibility during the afternoon indicate that the vertical transport was limited. Thus, the southwesterly flow at Mule Peak the following morning could be bearing high ratio free atmospheric dust.

15 May 1968

2.5

LOW

$\beta$

Weatherwise the 14th was similar to the 13th. Middle and high cloudiness were increasing, surface winds were strong southwesterly, convective activity was nil, and visibility remained good. In contrast, however, the surface winds remained moderate throughout the night. The key to the low ratio on the morning of the 15th appears to be the persistence of the wind field during the nighttime hours, thereby allowing the basin floor dust to be transported to the sampler by the westerly winds.

16 May 1968

3.4

HIGH

$\alpha$

The similarity in weather pattern continued, only this time the moderate afternoon southwesterly basin winds diminished significantly after sunset. The southwesterly winds at the sampler the following morning could thus be tapping the free atmosphere.

17 May 1968

2.7

LOW

$\beta$

Clear skies, strong southwesterly winds and blowing dust from noon to sunset characterized the 16th. At the sampler, westerly winds probably carried in the "blowing dust" of the previous afternoon thereby keeping the A/B ratio low.

18 May 1968

2.6

LOW

$\Delta$

Early on the morning of the 17th, a nearly stationary northwest-southeast oriented cold front moved slowly westward across the basin.

By noon, the resultant northerly flow over the basin had returned to westerly, but the speeds were light. Skies were clear except for scattered afternoon fair weather cumulus clouds. South southeasterly flow at the sampler the next morning was probably bringing in low ratio Sacramento Mountain boundary layer dust.

19 May 1968

3.1

LOW

Δ

On the 18th high clouds began to appear and basin winds were light and variable. South southeasterly winds at the sampler once again probably tapped boundary layer dust from the surrounding mountains.

## APPENDIX B

### ATMOSPHERIC DUST CONCENTRATIONS

The combined concentration (number per unit volume) of giant, large and Aitken particles was monitored with a General Electric Condensation Nuclei Counter\* (G. E. CNC), Cat. No. 112L428G1 with automatic ranging. Because of the relatively low concentrations of large and giant particles with respect to Aitken nuclei, the measured values actually correspond to Aitken nuclei.

The G. E. CNC, designated as C in Fig. 3 was located on a concrete platform near ground level along the northwest wall of the telescope building. Local sources of contamination appeared to be negligible. One obvious local source of Aitken nuclei was the motor generator (used to provide power for the Observatory at that time) located about 60 m northeast of the counter. However, during the periods when concentrations were recorded, the surface wind was such that little effect on the concentration from this source would be expected.

Hourly concentration (particles  $\text{cm}^{-3}$ ) means were determined and are displayed in Fig. 7. A reference line has arbitrarily drawn in at a concentration of  $10^4 \text{ cm}^{-3}$ . Concentrations ranged between  $10^3$  and  $10^5 \text{ cm}^{-3}$ . Generally the lowest values occur during the early morning prior to sunrise, the highest between sunrise and sunset.

Examination of the concurrent wind flow for the sampling periods revealed that the concentrations were sensitive to wind, both speed and direction, at the sampler and over the basin area. On the basis of the limited amount of data obtained, the following generalizations are offered:

- (1) The lowest concentrations were observed not only at night, but when the wind flow across the site ranged from east through south, i. e., from the forested areas of the Guadalupe Range. This is exemplified by the low concentrations during the mornings of 30 April and 5 May. On the former day the wind at the site veered from south to southwest at 0830 LST; on the latter day a similar veering did not occur until the afternoon. That the concentration remained low all during 4 May is attributed to the southeasterly flow at the sampler all day.

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\* Johnson, E. L., 1968: Condensation nuclei counter (G. E. Cat. No. 112L428). J. Rech. Atmos., III, 2<sup>e</sup>, 105-108.

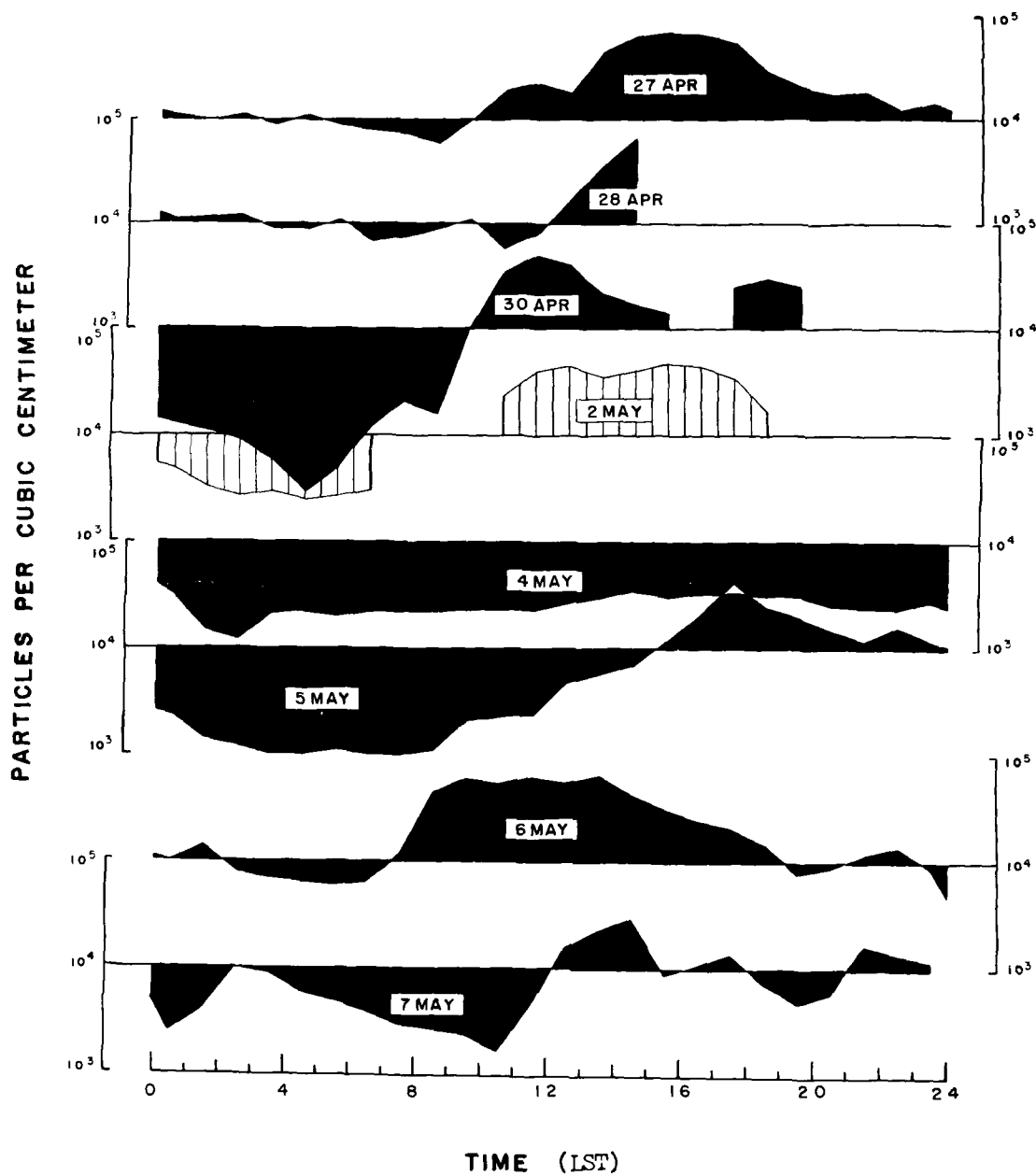


Fig. 7 Mean hourly concentrations of Aitken particles ( $\text{cm}^{-3}$ ), Mule Peak Observatory, 27 April - 7 May 1968.



- (2) The highest concentrations were noted with southwesterly to westerly flow, the magnitude being roughly directly proportional to the surface wind speed across the floor of the basin. An example of this is the early rise in concentration on 6 May. This feature is attributed to strong southwesterly winds across the basin which by 0800 to 0900 LST were already gusting from 10 to 15 m sec<sup>-1</sup>.

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<p>Six impactor and 99 membrane filter samples of atmospheric dust were collected atop a mountain in south central New Mexico during April and May 1968. Qualitative analysis of these samples by infrared absorption spectroscopy in the 4000 to 250 <math>\text{cm}^{-1}</math> wavenumber (2.5 to 40 <math>\mu</math> wavelength) range revealed that the positions and relative intensities of the absorption bands were dependent on the size fraction of the dust and on the time the sample was taken. Within the 1250 to 770 <math>\text{cm}^{-1}</math> (8 to 13 <math>\mu</math>) atmospheric window, the micron-sized (giant) particles exhibited a peak absorption at 1027 <math>\text{cm}^{-1}</math> (9.7 <math>\mu</math>), whereas the submicron (large) particles had their peak absorption at 1108 <math>\text{cm}^{-1}</math> (9.0 <math>\mu</math>). These two absorption bands are induced, respectively, by silicate clays and by ammonium sulfate. A temporal variation was observed in the ratio of the intensities of the 1027 <math>\text{cm}^{-1}</math> (9.7 <math>\mu</math>) silicate and the 1425 <math>\text{cm}^{-1}</math> (7.0 <math>\mu</math>) carbonate absorption bands of the giant particles. This ratio was high during the early morning, at times of convective activity and precipitation and at times of cold frontal passage from the east; it was low during the afternoon and at times of convective inactivity and no precipitation. The low ratio dust is attributed to advection of fresh soil particles from the exchange layer over the adjacent basin and mountains and the high ratio dust to advection of fresh soil particles from the Great Plains and aged soil particles from the overlying free atmosphere.</p>		

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